An integrated 520-600 GHz sub-harmonic mixer and tripler combination based on GaAs MMIC membrane planar Schottky diodes

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***Abstract*—We present here the design, development and test of an integrated sub-millimeter front-end featuring a 520-600 GHz sub-harmonic mixer and a 260-300 GHz frequency tripler in a single cavity. Both devices used GaAs MMIC membrane planar Schottky diode technology. The sub-harmonic mixer/tripler circuit has been tested using conventional machined as well as silicon micro-machined blocks. Measurement results on the metal block give best DSB mixer noise temperature of 2360 K and conversion losses of 7.7 dB at 520 GHz. Preliminary results on the silicon micro-machined blocks give a DSB mixer noise temperature of 4860 K and conversion losses of 12.16 dB at 540 GHz. The LO input power required to pump the integrated tripler/sub-harmonic mixer for both packages is between 30 and 50 mW.**

I. INTRODUCTION

FUTURE planetary missions dedicated to the remote sensing of planets' atmospheres such as Venus, Mars, Jupiter, Saturn and Titan could benefit from the high spectral resolution and high sensitivity achieved by sub-millimeter wave heterodyne receivers featuring Schottky diode devices. For instance, the 520-600 GHz frequency range is rich in emission and absorption lines, especially the water line at 557 GHz, whose detection and mapping is key to understand the atmospheric circulation of Mars and Jupiter [1].

For such long term planetary mission, the use of room temperature or passively cooled detectors are required since the mass and power budget of such missions is usually very constraining. It is also essential to integrate as much as possible the front-end elements in order to reduce size, mass and power consumption. First the integration of several devices functions such as mixing and multiplying can be performed. Second, the use of silicon instead of brass as packaging for devices can be implemented in order to further reduce the weights of the front-end.

We present here the design, fabrication and test of a combined 520-600 GHz sub-harmonic mixer (SHM) together with an 260-300 GHz frequency tripler. Both devices use the GaAs and metal MMIC membrane technology developed at JPL. Two types of packaging have been implemented: a metal based and a silicon micro-machined based one. Both architectures are presented and performance will be compared.

II. 520-600 GHZ SUB-HARMONIC MIXER / TRIPLER DESIGN

Previous studies have shown that multiplier and mixer devices can be combined together in a very compact architecture if ones can manage the harmonic generation of the multiplier and the mixing products of the mixer right [2]. In this paper, we present a novel tripler-sub-harmonic mixer combination in a compact arrangement. It involves two MMIC devices separated by a short piece of waveguide, as illustrated in Fig.1. For a tripler-sub-harmonic mixer combination, it is believed that this arrangement is very suited since the electrical properties of a waveguide are used to filter the unwanted harmonics of the tripler (i.e. 1st and 2nd harmonics).

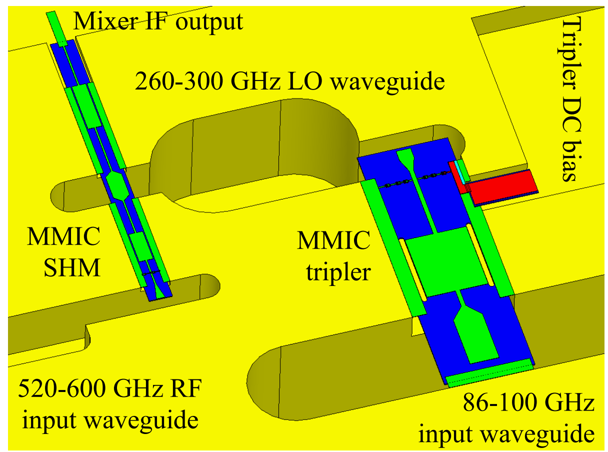

Fig.1: 3D view of an integrated 260-300 GHz MMIC tripler and 520-600 GHz MMIC sub-harmonic mixer.

The MMIC 260-300 GHz tripler device has already been described in [3]. The input matching circuit of the tripler was re-tuned from the original 260-340 GHz band to cover the bandwidth 260-310 GHz, resulting in a shorter waveguide matching network. The 520-600 GHz MMIC sub-harmonic mixer is scaled from [4] using the same balanced diodes architecture and design methodology. Both tripler and mixer devices were designed independently first and then coupled together to maximize their coupling through LO waveguide matching circuit. The intermediate LO waveguide between the tripler and mixer MMIC acts as a high-pass filter to reject the unwanted 2nd harmonic of the tripler, while being relatively short. The expected W-band input power required to pump the tripler and sub-harmonic mixer efficiently is estimated between 25 and 40 mW. The predicted DSB mixer conversion losses and noise temperature for both the silicon and metal milling blocks are shown in Fig.3 on the same graph as the metal block measurement results.

The main difference in the design of the 560 GHz sub-harmonic mixer and tripler combination for a split-waveguides structure compatible with conventional metal milling and the 3 dimensional waveguide structure compatible with silicon micro-machining technique is that the tripler W-band input waveguide-to-microstrip transition is rotated by 90 degrees and the input matching circuit is retuned accordingly.

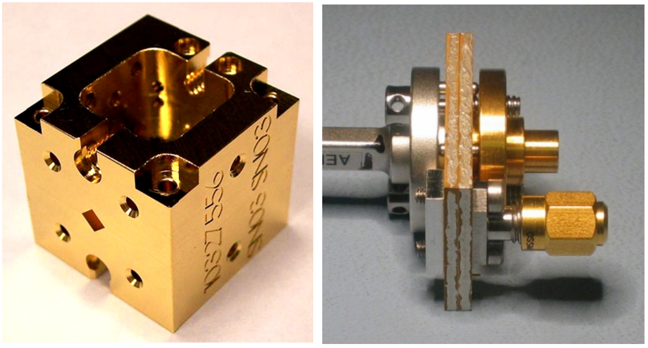

Fig.2: Views of the integrated 280 GHz tripler + 560 GHz sub-harmonic mixer blocks fabricated using conventional metal milling techniques (left hand side) and novel silicon micromachining techniques (right hand side).

Moreover, because of components availability at the time, the sub-harmonic mixer MMIC used in the silicon micro-machined block is tuned for the 540-640 GHz band rather than the 510-590 GHz band targeted by the MMIC in the metal block. Finally, the RF input waveguide in the silicon block also includes a 90 degrees one-step bend similar to [5] to re-align it to the input LO waveguide flange.

III. 560 GHz Receivers Fabrication and Test

A combined tripler/sub-harmonic mixer blocks using both conventional metal milling and silicon micromachining techniques have been fabricated and tested. The metal block, as shown in Fig.2 on the left hand side includes an integral diagonal feed horn [6], a WR-10 LO input waveguide flange, a 2-11 GHz IF transformer circuit connected to a K-type flange launcher, and a DC lead through filter for biasing the tripler. The silicon micro-machined block includes the same features apart from the feed horn which is external, as shown in Fig.2 on the right hand side, the tripler bias connector which is a K-type glass bead and the IF connector which is an SSMA type. As shown in Fig.2, the silicon micro machined block is slightly wider than the brass block (20x25mm^2 cross-section for the Si instead of 20x20 mm^2 for the brass) but is significantly thinner (3mm cross-section for the Si instead of 20mm for the brass).

The test system and procedure is described in [7]. The IF signal from the 560 GHz sub-harmonic mixer + tripler combination is fed into an 4-6 GHz self-calibrating IF chain with an isolator at the input and output. The IF power is recorded using an Agilent N1912 power meter connected to an Agilent thermocouple sensor.

The measurements performed on the metal machined block are presented in Fig.3, along with the predictions. As shown, the DSB mixer noise temperature is measured below 2100 K between 520 and 600 GHz with a best value of 1710 K at 590 GHz. The DSB mixer conversion losses are measured below 7 dB between 515 and 600 GHz with a best value of 5.3 dB at 590 GHz. The input power at W-band required for optimal performance is measured separately using a PM3 Erickson calorimeter between 30 and 50 mW.

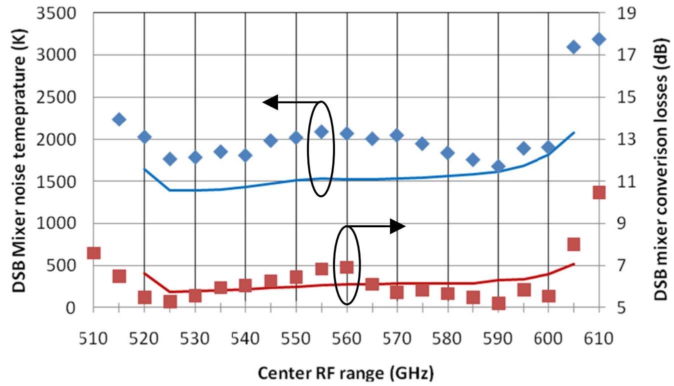

Fig.3: 560 GHz receiver front-end simulated (continuous lines) and measured (dotted curves) performance usign conventional machined block at 295 K ambient temperature. The top blue curve and dots are for the DSB mixer nosie temperature, the red curve and dots for the conversion losses.

The measurement results are in accordance with the simulation for the mixer conversion losses, and slightly lower for the mixer noise temperature (1 dB). This could be due to additional noise sources such as hot electron noise that can arise from high current densities in small anode areas and have not been included in this simulations. Further work is on-going to investigate the source of the discrepancy.

The measurements performed on the Silicon micro-machined block are very encouraging with a instantaneous frequency range extending from 525 to 600 GHz, a best DSB mixer noise temperature of 4860 K and best DSB mixer conversion losses of 12.16 dB at 540 GHz. Although the values are more than 3 dB worse than the measurements done with the metal machined block, the operating frequency range and required LO power measured separately between 30 and 50 mW are similar. This discrepancy in the results could be attributed in part to the higher than expected surface roughness of the RF input waveguide in the silicon micro-machined block. Work is in progress to resolve this issue.

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